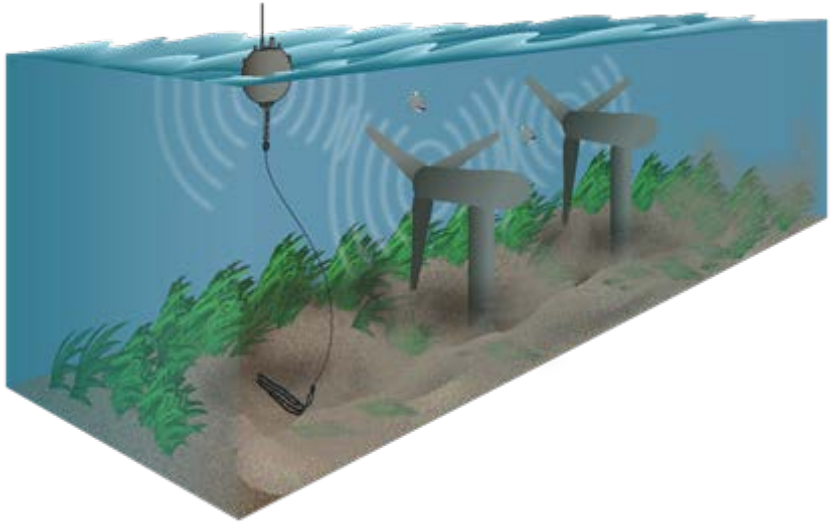


NoiseSpotter: A cost-effective, real-time acoustic characterization and localization system

EE0007822

Marine and Hydrokinetics Program

October 9, 2019

Kaus Raghukumar

Integral Consulting Inc.

Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Summary

"NoiseSpotter" helps efficiently evaluate potential acoustic effects of MHK projects. NoiseSpotter geolocates sources of sound, allowing for the ability to discern MHK device sounds relative to other confounding sounds in the environment, while providing location estimates of nearby marine mammals for environmental mitigation purposes. The NoiseSpotter also measures acoustic particle velocity that can help address growing concerns about particle velocity effects on fishes and invertebrates.

Project Objective & Impact

- Characterization of MHK noise requires distinguishing device sounds from ambient environmental sounds using geolocation techniques
- A major objective of this work is the development of a low-cost, real-time acoustic measurement system to monitor and characterize MHK and ambient environmental sounds
- The final project product is a 3D array of acoustic sensors coupled to a surface buoy for near real-time telemetry of acoustic data digests to a cloud-based server.

Project Information

Project Principal Investigator(s)

Kaus Raghukumar
Grace Chang
Craig Jones

WPTO Lead

Dana McCoskey

Project Partners/Subs

Proteus Technologies
Sandia National Labs
Noise Control Engineering
HT Harvey and Associates

Project Duration

- Project Start Date: November 2016
- Project End Date: December 2019

Alignment with the Program

Marine and Hydrokinetics (MHK) Program Strategic Approaches

Data Sharing and Analysis

- Foundational and Crosscutting R&D
- Technology-Specific Design and Validation
- **Reducing Barriers to Testing**

Alignment with the MHK Program

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Reducing Barriers to Testing

- Enable access to world-class testing facilities that help accelerate the pace of technology development
- Work with agencies and other groups to ensure that existing data is well-utilized and identify potential improvements to regulatory processes and requirements
- **Support additional scientific research as needed, focused on retiring or mitigating environmental risks and reducing costs and complexity of environmental monitoring**
- Engage in relevant coastal planning processes to ensure that MHK development interests are equitably considered

This project is developing an acoustic monitoring system to detect and characterize baseline noise and low level continuous noise from MHK device operations and support geolocation of detected noise(s) relative to source(s). The NoiseSpotter enables cost-effective, real-time acoustic monitoring of an operational MHK device relative to ambient environmental noises. The technology provides a technical basis for MHK developers seeking to streamline the permitting process by helping to mitigate concerns about the potential for MHK device noise to alter marine mammal or fish behavior.

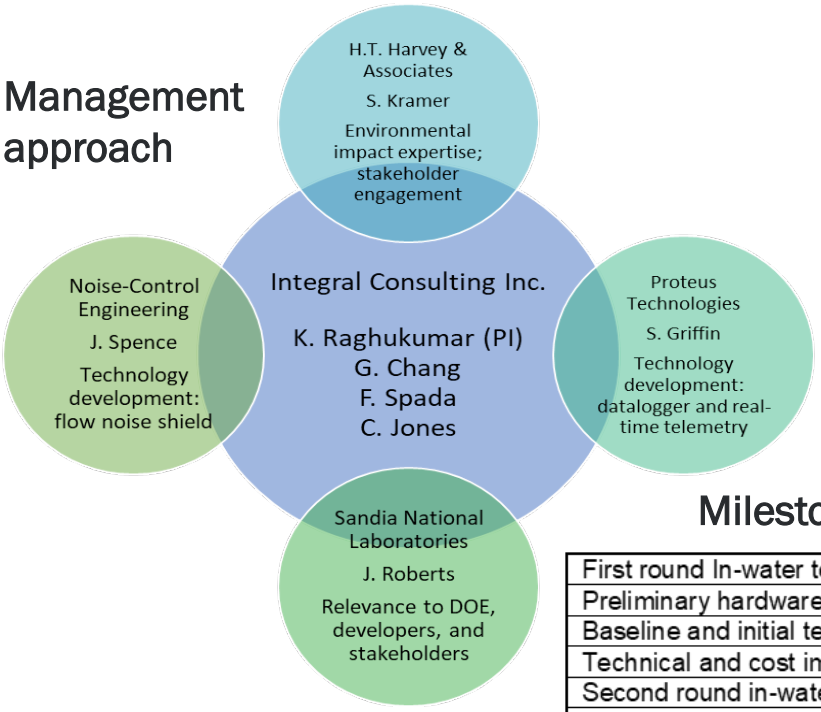
Project Budget

Total Project Budget – Award Information		
DOE	Cost-share	Total
[$745,649]	[$199,666]	[$945,315]

FY17	FY18	FY19 (Q1 & Q2 Only)	Total Actual Costs FY17–FY19 Q1 & Q2 (October 2016 – March 2019)
Costed	Costed	Costed	Total
[$110,305]	[$411,184]	[$188,829]	[$710,318]

Management Approach

Management approach



Milestone Gantt chart

	BP1 (Months 1-12)				BP2 (Months 13-24)				BP3 (Months 2		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
First round In-water testing plan											
Preliminary hardware design											
Baseline and initial testing with known source											
Technical and cost improvement plans											
Second round in-water testing											
Flow noise removal system development											
Data logger and power system hardware											
Location estimation algorithm development											
Integrated standalone NoiseSpotter powered with on-board storage tested in-water											
Technical and cost performance analysis update											
Finalize VSA design											
Real-time data telemetry software demonstration											
Creation of data digests on board NW											
Third round field testing in energetic environment											
Evaluation of quantitative metrics for baseline, initial, second round testing and state-of-the-art											
Final reporting											

Technical Approach

Critical success factors

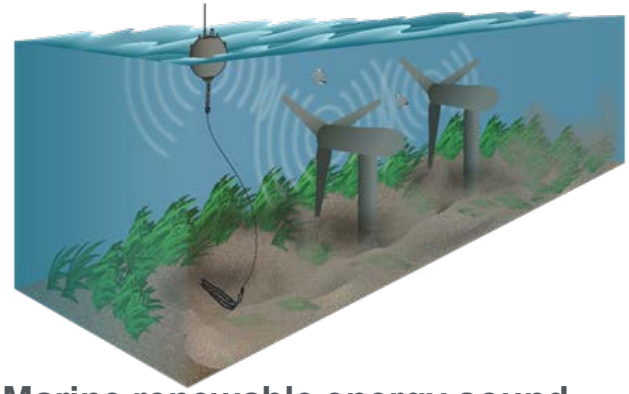
- Location estimation
- Real-time reporting
- Target price
- Flow noise removal
- Ease of operations

Performance category	Target metric
Detection frequencies	40 Hz to 3 kHz
Location estimation	Within larger of 25 m or 2% of range between source and measurement
Ambient noise removal	Coherent processing across multiple sensors suppresses incoherent ambient noise
Flow noise removal	>3 dB
Clock	All sensors synchronized to buoy-based GPS clock
Data communication system	6 kb transmission of key data metric digest (see below); satellite range: unlimited; < 1% data drop-outs; automatic data queuing; automatic communication system re-establishment
Onboard data storage	48 GB/day @ 25 kHz for 21 days
Power budget	2 W of electrical power including acoustic sensors, analysis, and storage
Operational duration	Autonomously for 14 days (limited by data storage); indefinite for data digests only (limited by marine fouling on the buoy and mooring system)
Operational environment	Any: inland waters, harbors, surf zone, coastal ocean, open ocean; low to high energy
Data presentation and interpretation	Short data digests allow for rapid decision making. Digests contain peak exceedance levels, RMS sound pressure level, location estimates with error bounds.
Cost	<$30,000

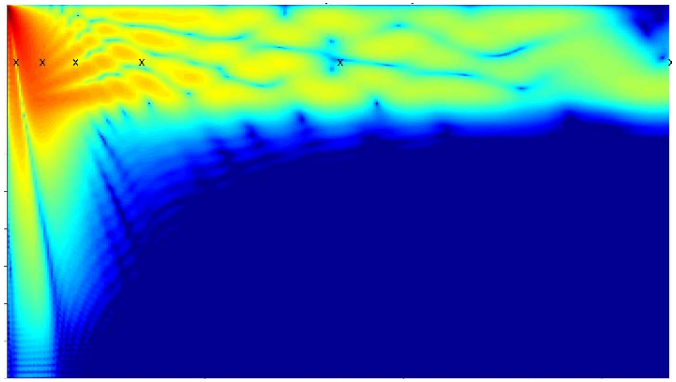
End-User Engagement and Dissemination Strategy

- **Introduced to regulators and stakeholders at multiple conferences**
  - Marine Energy Technology Symposium (2018,2019)
  - Offshore Technology Conference (2019)
  - Underwater Acoustics Conference and Exhibition, 2019
  - Effects of Noise on Aquatic Life, 2019
- **Industry and regulator needs surveyed and addressed during Q8 in-water testing**
- **Aim of surveys**
  - Ensure NoiseSpotter hardware and operations is appropriate for developers
  - Data output is useful for baseline site characterization and operational deployments

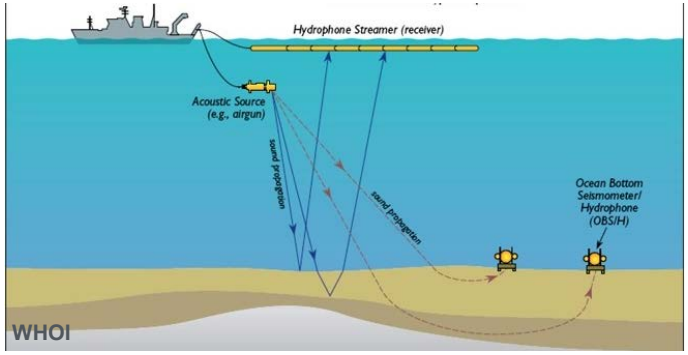
Technical Accomplishments - Motivation



Marine renewable energy sound characterization



Sound source verification and characterization

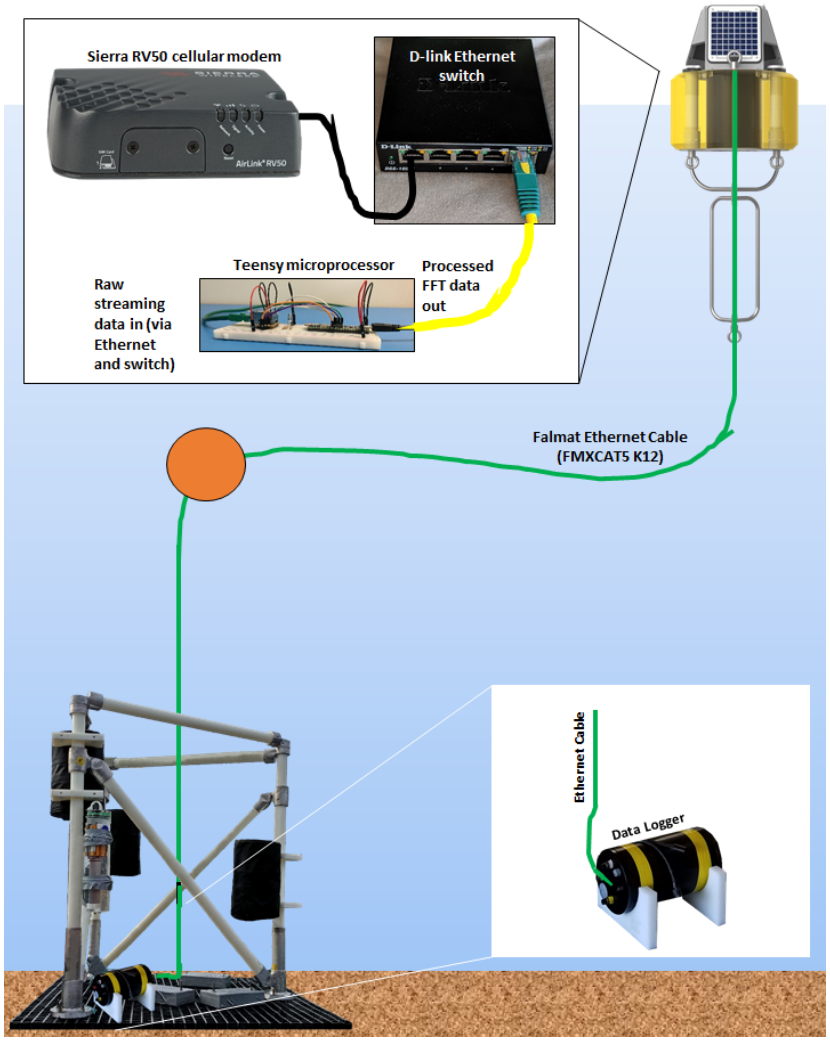


PAM in exclusion zones

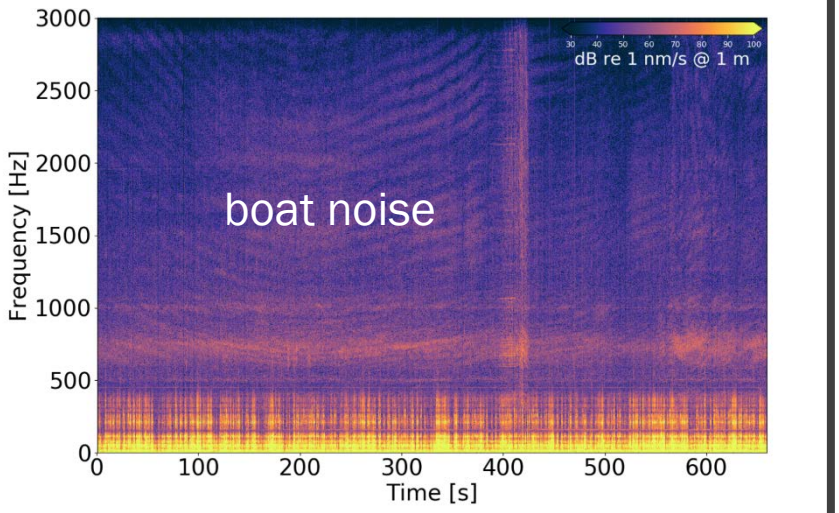
Particle motion measurements

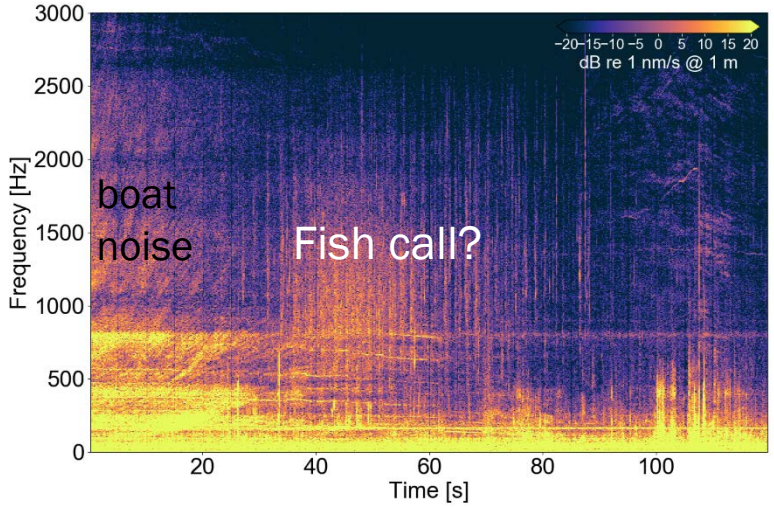
Technical Accomplishments - Overview

- **Vector sensor array with real-time telemetry**
  - 3D pressure and particle motion measurements
  - Acoustic characterization and source localization
- **Operating environment**
  - Tidal regions
  - Wave-rich regions
  - 200 m water depth (no telemetry), 75 m (with telemetry)
- **Technical specifications**
  - Frequency range (50 Hz to 3 kHz)
  - Sampling frequency (20 kHz, 16-bit depth)
  - Array spacing (1 m horizontal, 25 cm vertical)

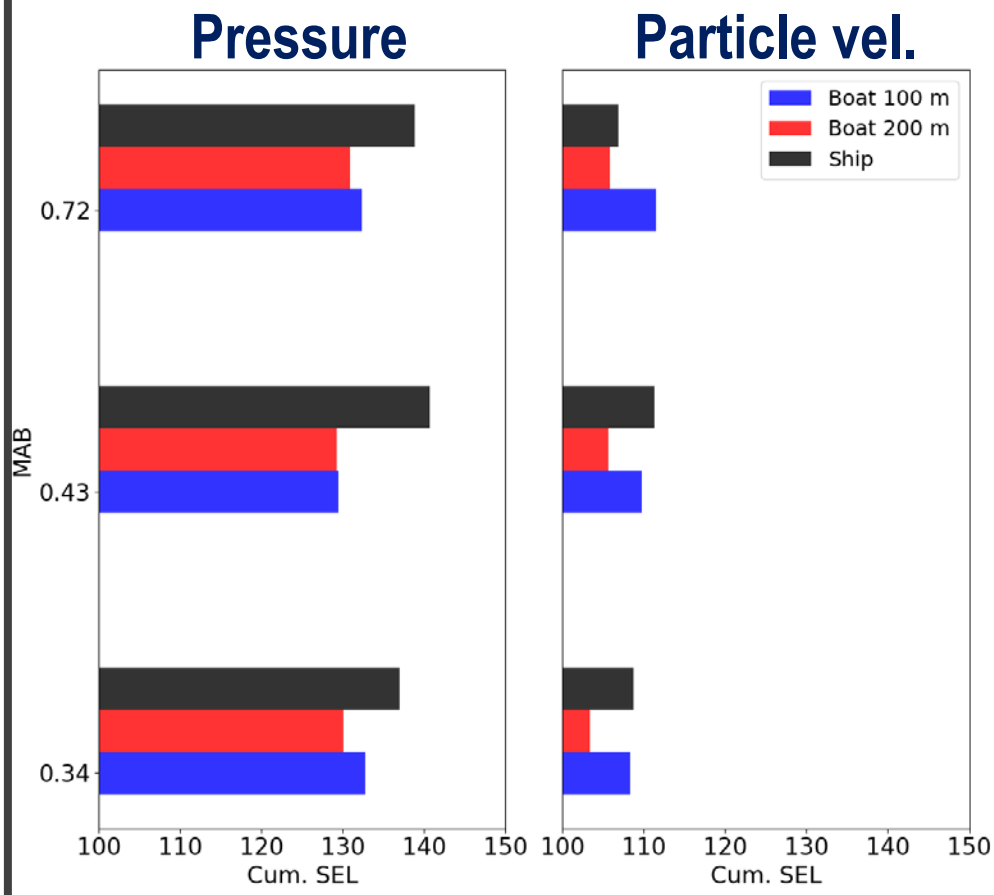


Technical Accomplishments – Measurement examples

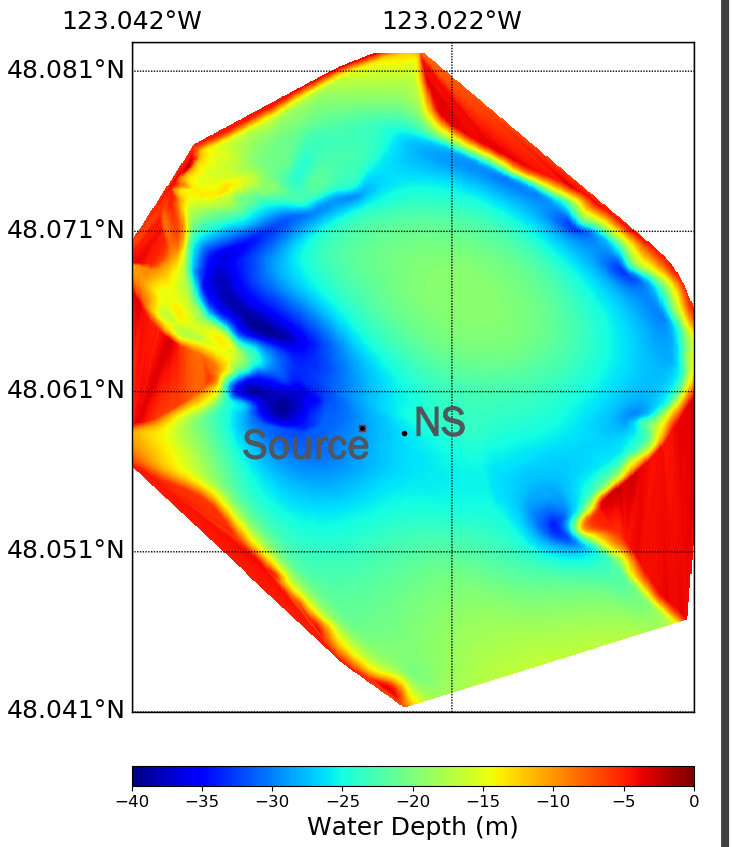


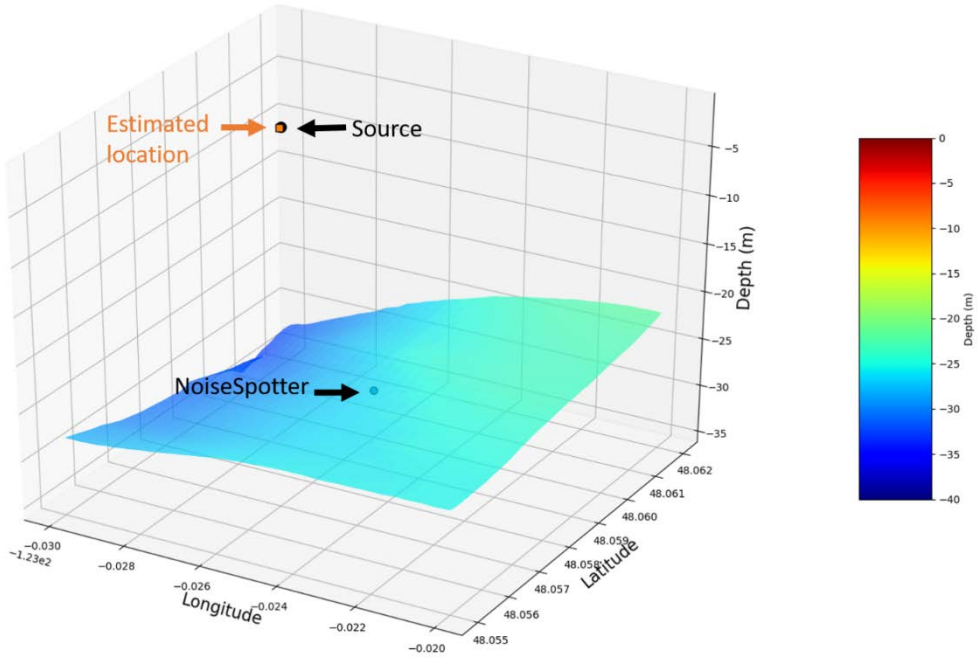


Pressure and particle velocity for container ship versus a small boat

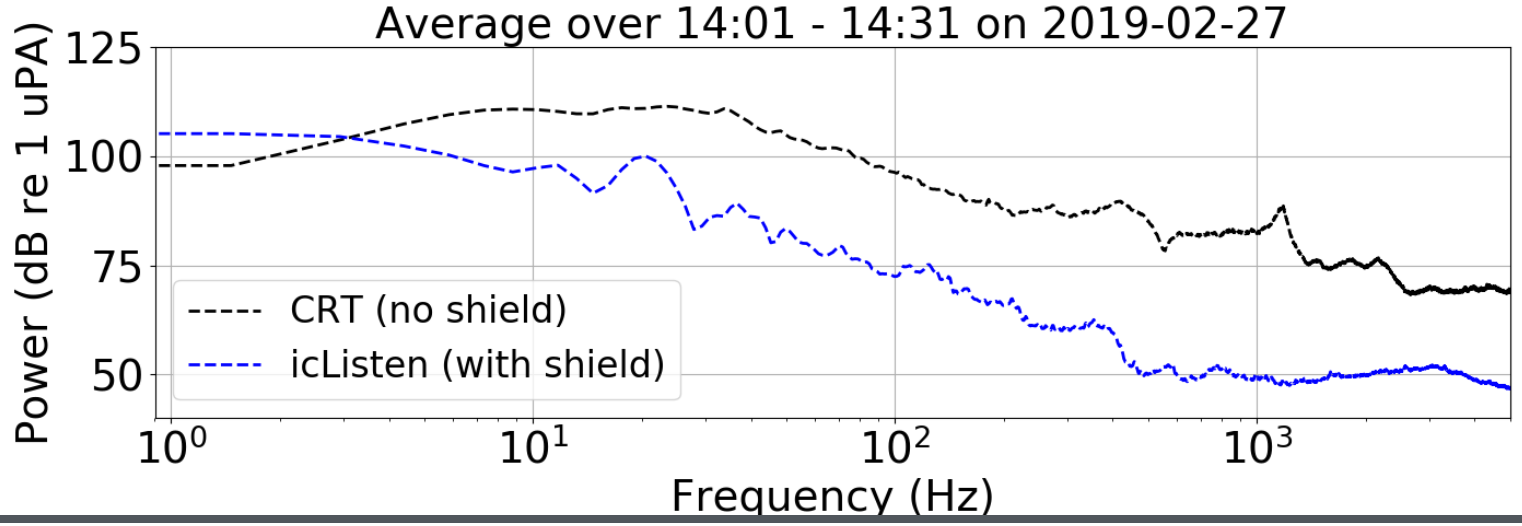


Technical Accomplishments – Location estimation





Technical Accomplishments – Flow noise removal

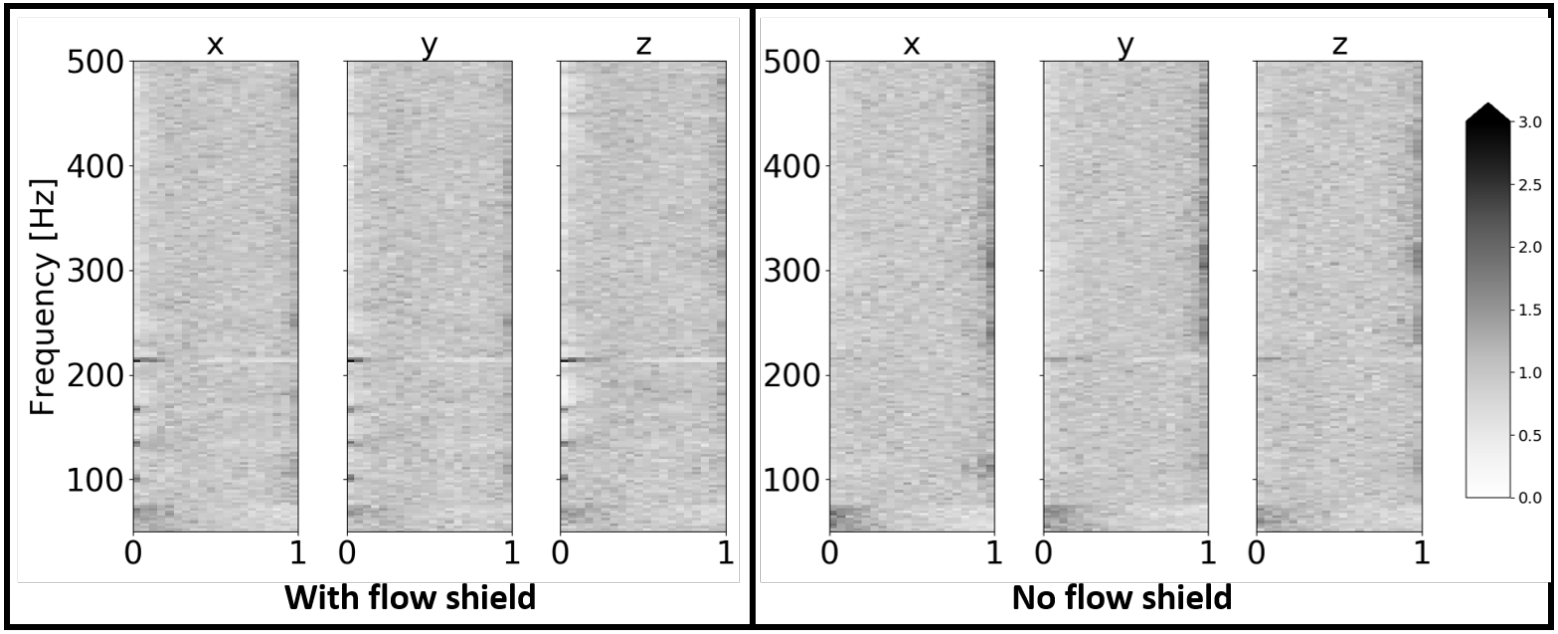


Technical Accomplishments – Flow noise removal efficiency

- Relationship between particle velocity cross-spectra and active & reactive intensity spectra

$$M_x = \frac{|Q_{yz}(\omega)| - \left|\left(\frac{C_{p[x,y,z]}(\omega) \times Q_{p[x,y,z]}(\omega)}{S_{pp}(\omega)}\right)_x\right|}{|Q_{yz}(\omega)| + \left|\left(\frac{C_{p[x,y,z]}(\omega) \times Q_{p[x,y,z]}(\omega)}{S_{pp}(\omega)}\right)_x\right|}$$

- Values of M_{21} that diverge from zero indicate non-acoustic contamination
- Compare distribution of M_{21}, M_{22}, M_{23} over 30-minute periods with and without flow shields



Technical performance analysis

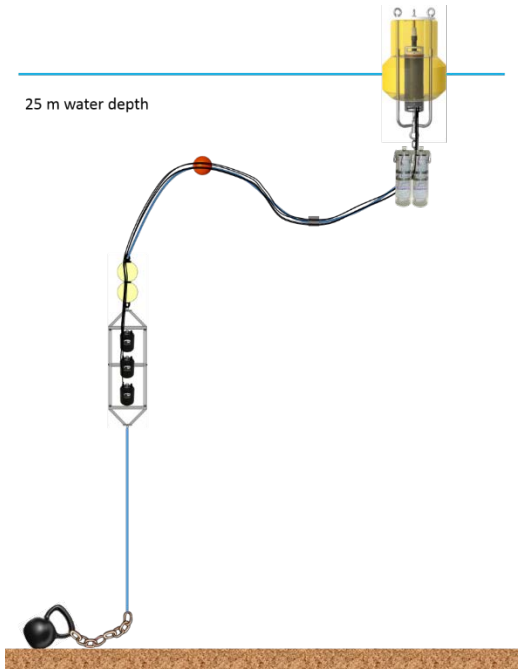
Technical performance analysis

Engineering/Data issue	Target score and metrics by end of BP2	Current score
Array frame motion	1 <5° movement in pitch, roll, and yaw in energetic seas	1 <5° movement in pitch, roll, and yaw in energetic seas
Signal losses	0 2 dB signal loss	0 2 dB signal loss
Unwieldiness of system	2 Two personnel required for deployment and recovery	2 Two personnel required for deployment and recovery
Flow noise removal system	2 Flow noise reduction of 2 dB at <200 Hz and <1 dB signal loss at >1 kHz	1 Flow noise reduction of >15 dB at <200 Hz and <1 dB signal loss at >200 Hz
Data quality of M20-040	0 Zero dB degradation in signal to noise ratio	0 Zero dB degradation in signal to noise ratio
Data logger noise	2 VSA signals comparable to BAR data	2 VSA signals comparable to BAR data
Feasibility of location estimation	4 Bearing estimates <100 m of known source	3 Bearing estimates well within 100 m of known source

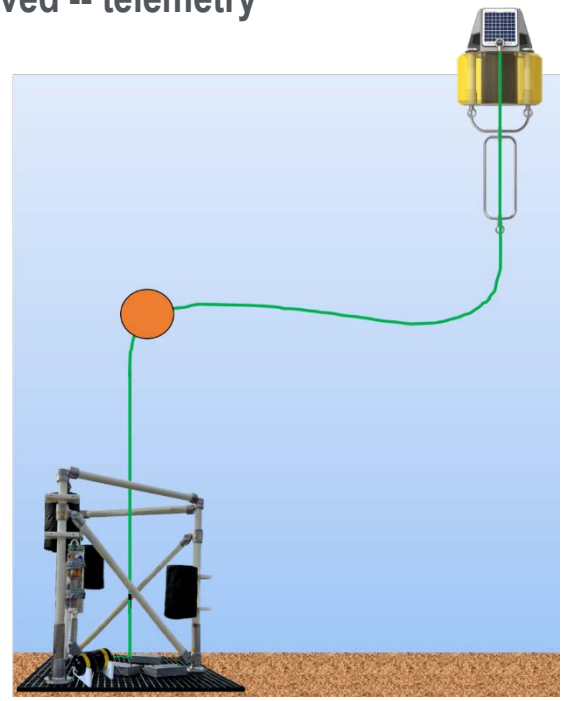
Cost performance analysis

Baseline

Initial – no telemetry



Improved -- telemetry



Cost performance analysis:

Baseline (broadband autonomous hydrophone)

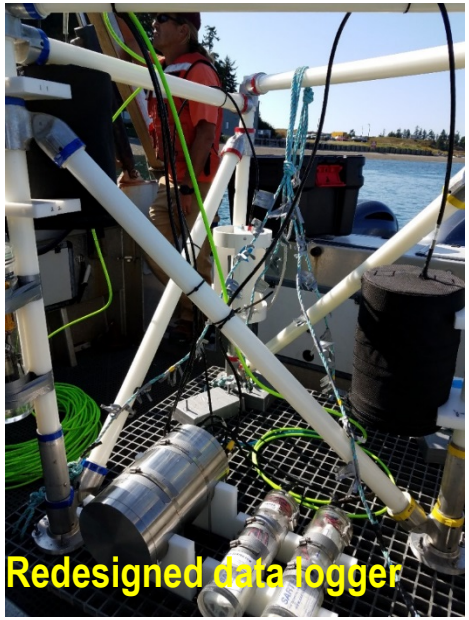
Initial (NoiseSpotter, no telemetry): 20% savings over baseline

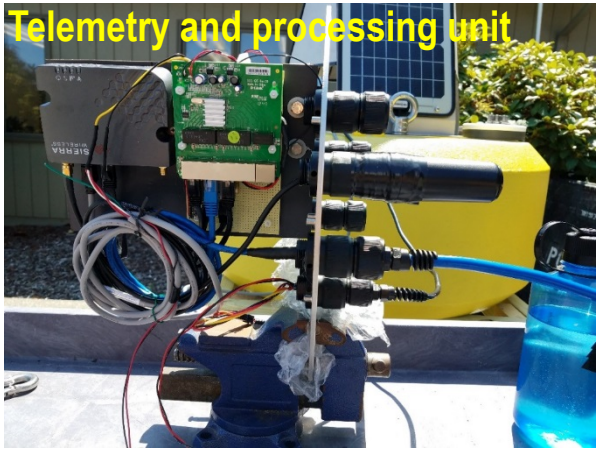
Improved (NoiseSpotter with telemetry): 50% savings over baseline

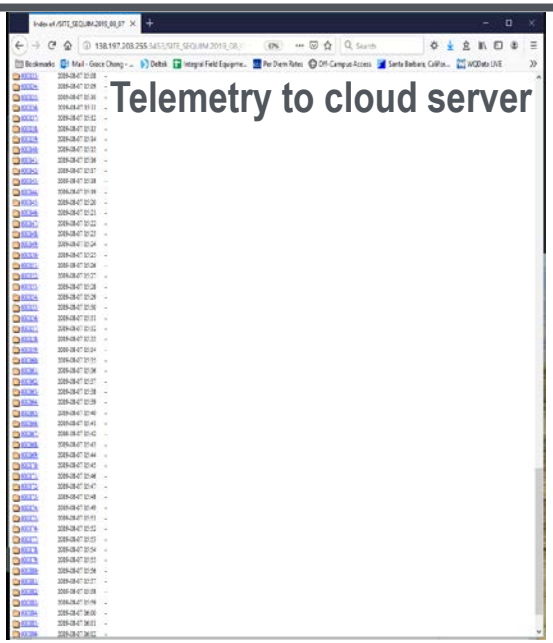
Technical Accomplishments- Recognition/publications

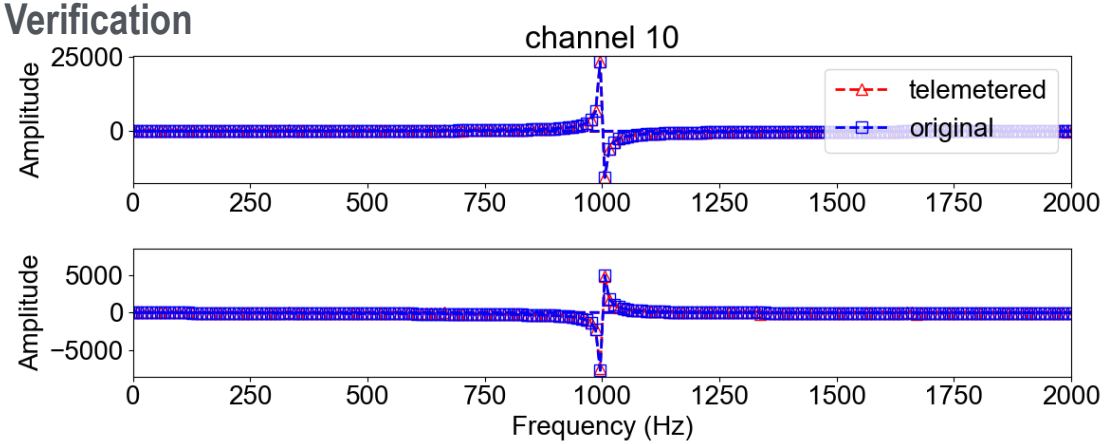
- NoiseSpotter is the only commercial vector sensor array with real-time telemetry
- Featured on on DOE WPTO semiannual stakeholder webinar (February 7, 2019)
- Conference papers
  - "Raghukumar, K. G. Chang, F. Spada, and C. Jones. 2019. Performance characteristics of the NoiseSpotter: An acoustic monitoring and localization system. A. Cooper and P. Gibbs (Eds.). Offshore Technology Conference (OTC2019). Houston, TX.
  - Raghukumar, K., G. Chang, F. Spada, C. Jones, J. Spence, S. Griffin, and J. Roberts. 2019. Performance characteristics of a vector sensor array in an energetic tidal channel. Papadakis et al. (Eds), Proceedings of the Underwater Acoustics Conference & Exhibition (UACE). Crete, Greece.
  - Raghukumar, K., G. Chang, F. W. Spada, and C. A. Jones. 2019. NoiseSpotter: A rapidly deployable acoustic monitoring and localization system. Vicinanza et al. (Eds), Proceedings of the 13th European Wave and Tidal Energy Conference. Naples, Italy.
- Novel instrumentation
  - Synchronous multichannel low noise, low power, extended storage data logger

Progress Since Project Summary Submittal



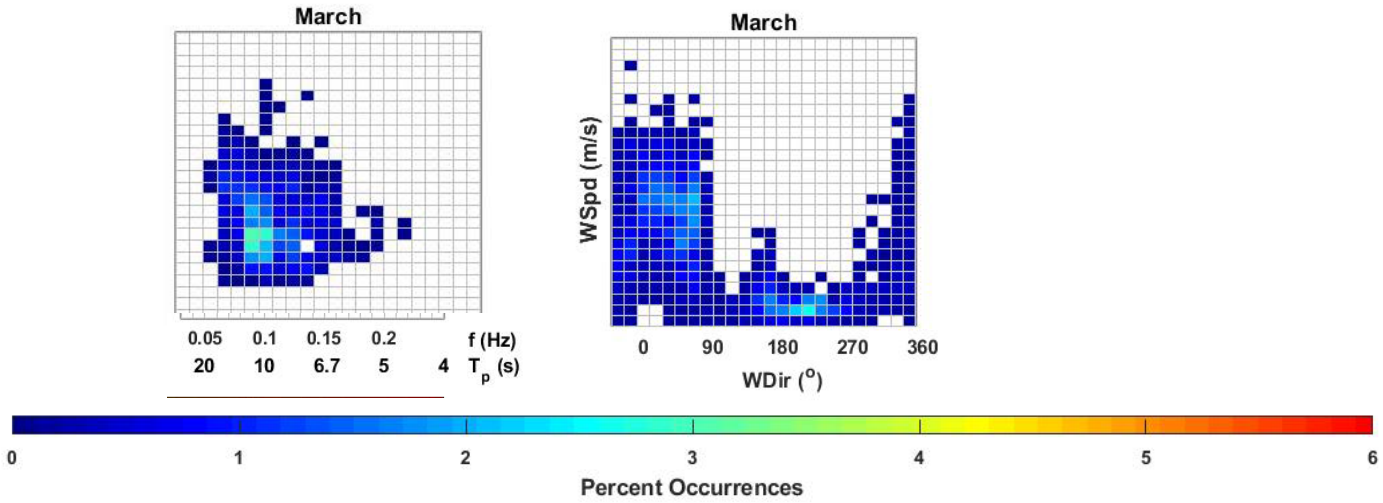






Future Work

- *Planning for WETS testing*



- *Evaluation of telemetry data mismatch*
- *Final reporting*